60 mA CARBON BEAM ACCELERATION WITH DPIS

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Abstract

We have studied "direct plasma injection scheme (DPIS)" since 2000. This new scheme is for producing very intense heavy ions using a combination of an RFQ and a laser ion source. An induced laser plasma goes directly into the RFQ without an extraction electrode nor any focusing devices. Obtained maximum peak current of Carbon beam reached 60 mA with this extremely simple configuration.

CONCEPT OF THE DPIS

Direct Plasma Injection Scheme (DPIS) has great advantages to produce pulsed highly charged heavy ions with an very simple structure. Induced plasma by a laser shot initially has a few hundred keV velocity normal to a solid target surface and can move directly into an RFQ entrance not passing through an extraction electrode. With this configuration, space charge effect can be avoided and we can utilize high density of the laser plasma for making intense ion beams.

Since 2001, we have had experiments to verify the DPIS using an existing RFQ in TITech, Tokyo. Obtained maximum current of Carbon beam was 9.2 mA and this value was well agreed with our simulation[1,2]. Upon this experience, a dedicated new RFQ was built and tested.

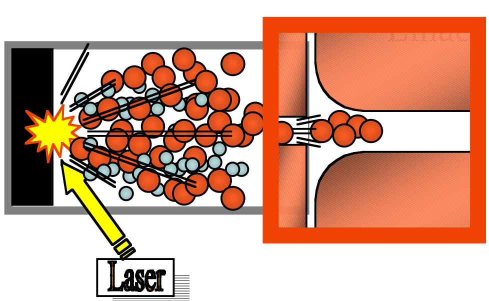

Figure 1: The scheme of direct plasma injection.

THE NEW RFQ FOR INTENSE HEAVY IONS

The new RFQ was constructed at Institute for Applied Physics, Goethe University, Frankfurt. This RFQ was designed to accelerate Carbon 4+ and 6+. A goal current was set to 100 mA with C^{4+}. Operation frequency was chosen as 100 MHz by availability of an RF amplifier system. Total vane length was decided as 2 m considering future modification however output beam energy is 100 keV/u limited by a radiation safety regulation in the experimental area. The beam is accelerated up to 100 keV/u within first 1.42 m section and then transported through un-modulated vanes to the end of the RFQ. In the un-modulated section, the accelerated beam is completely de-bunched and this will help to reduce space charge effect in an analyzing section. The input energy of the beam is a very important value, because in DPIS a high voltage biased slit is placed at the entrance of the RFQ and might cause discharge. The injection beam energy was set to 60 kV for C^{4+}. A picture and summarized design parameters of the RFQ are shown in Fig. 2 and Table 1 respectively. To confirm the particle dynamics in the RFQ, PteqHI was used. This code was developed by one of authors and can simulate multiple charge states beam simultaneously[3].

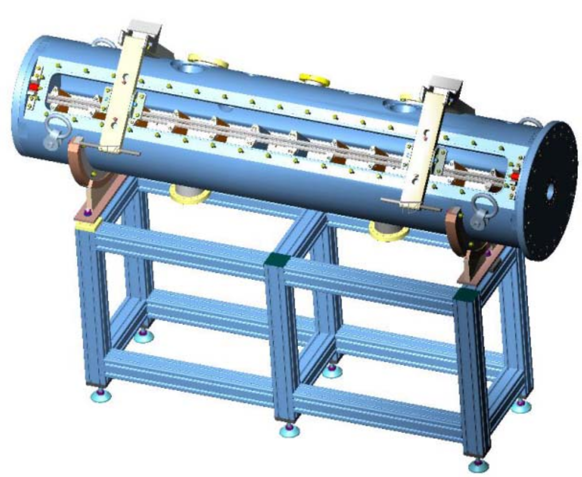

Figure 2: 100 MHz 4 rod RFQ for the DPIS.

Table 1 : Basic design parameters of the RFQ

Frequency	100 MHz
Total length	2.0 m
Modulated vane length	1.42m
Limit of intervane voltage	120 kV
I_{out} at 100 mA C^{4+} in	76 mA
Saturated I_{out}, C^{4+} only	155 mA
I_{in} for saturated I_{out}	~300 mA
Acceptance	0.14 cm.rad
Aperture	0.655 cm (βλ/3)

LASER PLASMA PRODUCTION

A CO_2 laser was used and the emitted energy to the carbon target was measured as 1.2 J with 85 ns (FWMS) of pulse width. Before injecting the beam into the RFQ, the contents of the ablated plasma were examined. A static electric deflector was uses as an analyzer which separated charge states of ions. Also we can get some information about expanding velocities of each charge states from the detector signal. The experimental set up and a typical waveform from the detector are shown in Figs. 3 and 4.

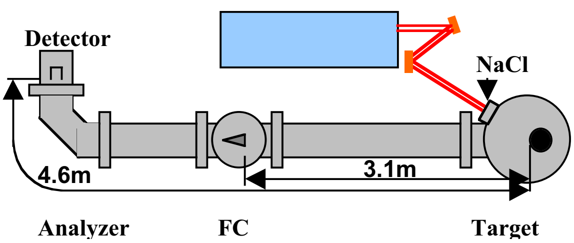

Figure 3: The experimental set up for the plasma measurement.

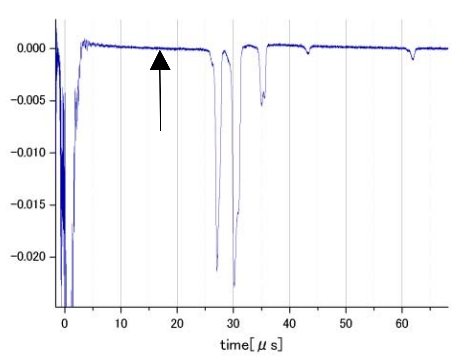

Figure 4: The signal from the detector.
In this case, a secondary electron multiplier was used.

The experiment shows that this condition of the laser system produces mainly C4+ (50 %) and rest of the ions were comprised with C5+ (35 %) and C3+ (15%). We can assume that these three charged states ions are injected to the RFQ. No hydrogen ion was observed.

LASER ION SOURCE

Ion source parts, including the plasma production solid target and the space which will be filled by the ablated plasma, have to be isolated electrically and to be kept at high voltage which corresponds to the beam injection energy of the RFQ. 60 kV is applied to the ion source part and this voltage is too high to insulate in the air condition. Therefore, high voltage parts are located only in a vacuum box and are not shown from outside. The fed energy to the plasma is provided only by laser shot. This means that both a large terminal stage and safety fence are not needed and the ion source part can be made extremely compact and simple. Behind the vacuum box, laser beam is injected through double NaCl windows and guided to the high voltage region. A concave mirror reflects and focuses the laser beam on to the Carbon target. Then plasma is induced and expanded towards to the RFQ. Finally the expanding plasma which can be accommodated by the high voltage slit is injected to the RFQ. According to the plasma production experiment, with ID = 6 mm slit, 160 mA of C5+, 210 mA of C4+ and 70 mA of C3+ are injected simultaneously into the RFQ at the current peak.

BEAM TEST

The acceleration test was done at NIRS. The fed RF power was 200 kW which is optimized for C4+ acceleration. A faraday cup was placed just after the RFQ which captured all the current passing through the RFQ including un-accelerated ions. A electro static analyzer was located at downstream of the RFQ, however the analyzer only has vary small acceptance. Therefore the measured current after the analyzer only shows relative current of the accelerated charge states. Figure 5 is a photo of the RFQ and the analyzer.

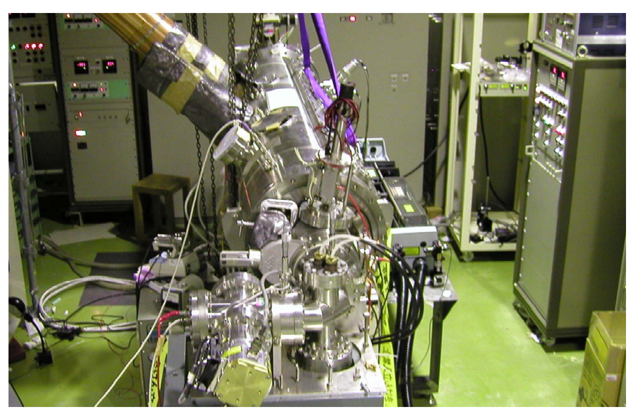

Figure 5: The RFQ and the analyzer.

A typical signal wave from the faraday cup before the analyzer is shown in Fig. 6. The peak current reached more than 60 mA. According to the analyzed currents, the accelerated current is only corresponds to first 2 μs. The signal after the 4 μs seems un-accelerated lower charged

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states ions which was captured transversely but was not captured by the acceleration buckets. The time of flight information of the first spike is quite consistent with our expectation. The analyzed current ratio shows that the accelerated current contains C 3+ less than 5 %. About 60 % of the accelerated current is occupied by C4+.

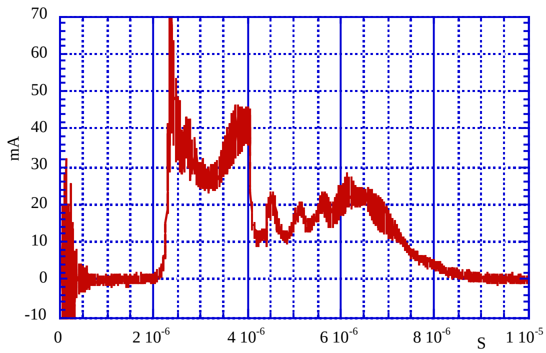

Figure 5: The faraday cup signal.

CONCLUSION

It was proven that the DPIS produces and accelerates very intense carbon ions. The maximum peak current was reached more than 60 mA. It should be noted that the current was measured after the RFQ acceleration and was not before injection of the RFQ.

We plan to test various types of laser systems and heavier species. Also we will test solid proton or argon target on a cryo-cooler head. We believe this technique can be utilized in many applications.

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